A NLO analysis on fragility of dihadron tomography in high energy AA collisions

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Abstract. The dihadron spectra in high energy AA collisions are studied within the NLO pQCD parton model with jet quenching taken into account. The high p_T dihadron spectra are found to be contributed not only by jet pairs close and tangential to the surface of the dense matter but also by punching-through jets survived at the center while the single hadron high p_T spectra are only dominated by surface emission. Consequently, the suppression factor of such high-p_T hadron pairs is found to be more sensitive to the initial gluon density than the single hadron suppression factor.

One of the most exciting phenomena observed[1] at the Relativistic Heavy ion Collider (RHIC) is jet quenching[2]—a hard probe of a strongly-interacting quark gluon plasma in high energy heavy ion collisions. The observed suppression of large p_T hadron spectrum is caused by the total parton energy loss which is related to the average gluon density along the jet propagation path and the total propagation length[3]. Therefore, measurements of large p_T hadron suppression can be directly related to the averaged gluon density. Here we will employ a NLO pQCD parton model[4] to study the suppression of both single and dihadron spectra due to jet quenching. Different from the previous LO study[3], because the number ratio of gluon/quark jets is larger in NLO than in LO calculation and the energy loss of a gluon jet is assumed to be 9/4 larger than that of a quark jet, NLO contribution will behave with stronger quenching effect than LO contribution (see Fig. 4, $R_{AA}^{NLO} < R_{AA}^{LO}$, $I_{AA}^{NLO} < I_{AA}^{LO}$). In particular, we will check the robustness of back-to-back dihadron spectra as a probe of the initial gluon density when single hadron spectra supression become fragile[5].

Within a NLO pQCD parton model [4], large p_T particle production cross section in $N+N$ collisions can be expressed as a convolution of NLO parton-parton scattering cross sections, parton distributions inside the collided nucleons and parton fragmentation functions (FF). In order to study large p_T particle production in $A+A$ collisions, one can extrapolate $N+N$ cross section to $A+A$ collisions. The effect of jet quenching in $A+A$ collisions is incorporated via the modified jet fragmentation functions due to radiative parton energy loss in dense medium [3, 6]. The modified jet fragmentation

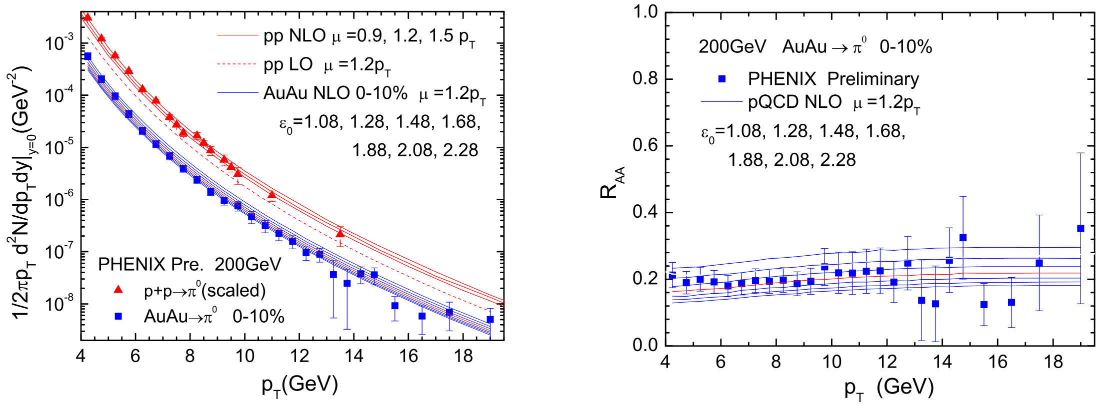

Figure 1. The single π^0 spectra (left) in $p+p$ and in central $Au+Au$ collisions, and the nuclear modification factors (right). The data are from Ref.[7].

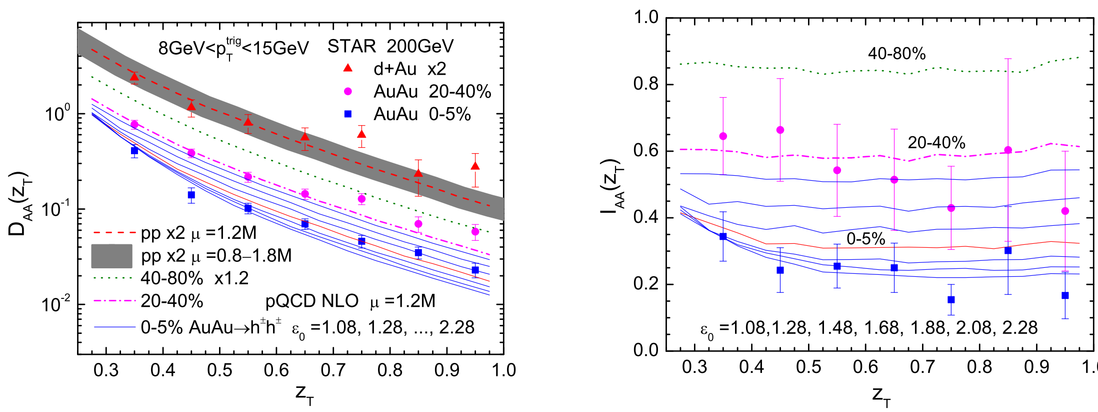

Figure 2. The associated hadron spectra (left) of dihadron in $p+p$ and $Au+Au$ collisions, and the suppression factor (right) of dihadron. The data are from Ref.[8].

functions are in turn characterized by the average radiative parton energy loss which is proportional to the initial gluon density. An energy loss parameter ϵ_0 [3, 6] is introduced in following numerical calculations, which is proportional to the initial gluon density ρ_0.

By comparing NLO results with data in Fig. 1 and Fig. 2, we get Fig. 3 by choosing the factorization scale as $\mu = 1.2p_T$ for single hadron and $\mu = 1.2M$ for dihadron, and the energy loss parameter $\epsilon_0 = 1.68\text{GeV/fm}$ in $A+A$ collisions. M is the invariant mass of the dihadron and $D_{AA}(z_T)$ was introduced in Ref. [3] as a function of $z_T = p_T^{\rm asso}/p_T^{\rm trig}$, which is the associated hadron spectrum with a triggered hadron. The dihadron suppression factor in Fig. 2 is given by $I_{AA}(z_T) = D_{AA}(z_T)/D_{pp}(z_T)$.

For single hadron case, because of jet quenching, the dominant contribution to the measured hadron spectra at large p_T comes from those jets that are initially produced in the outer corona of the overlap region toward the direction of the detected (or triggered) hadron's momentum. This is clearly illustrated in the left plot of Fig. 3 by the spatial

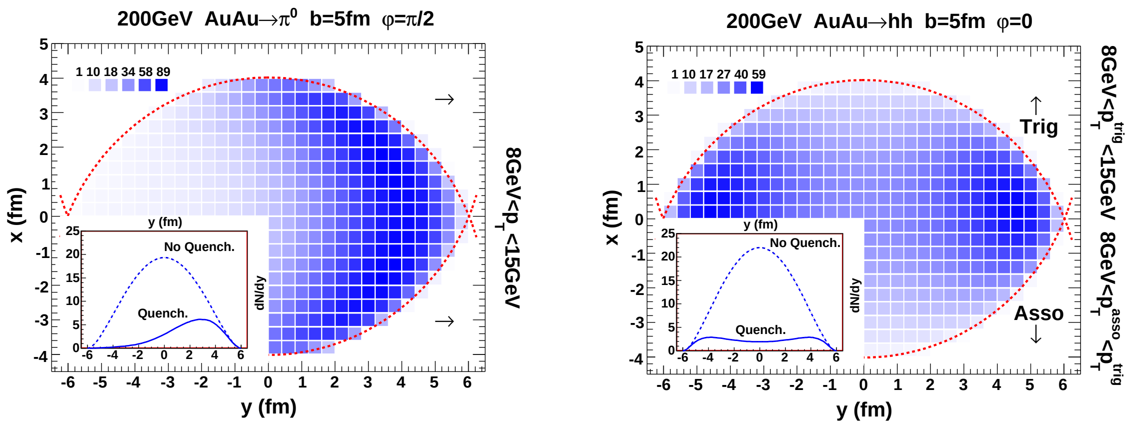

Figure 3. Spatial transverse distribution (arbitrary normalization) of the produced jets contributing the single hadron (left) along $\varphi = \pi/2$ and the dihadron (right) along $\varphi = 0$ and π. The insert is the same distribution projected onto the y-axis.

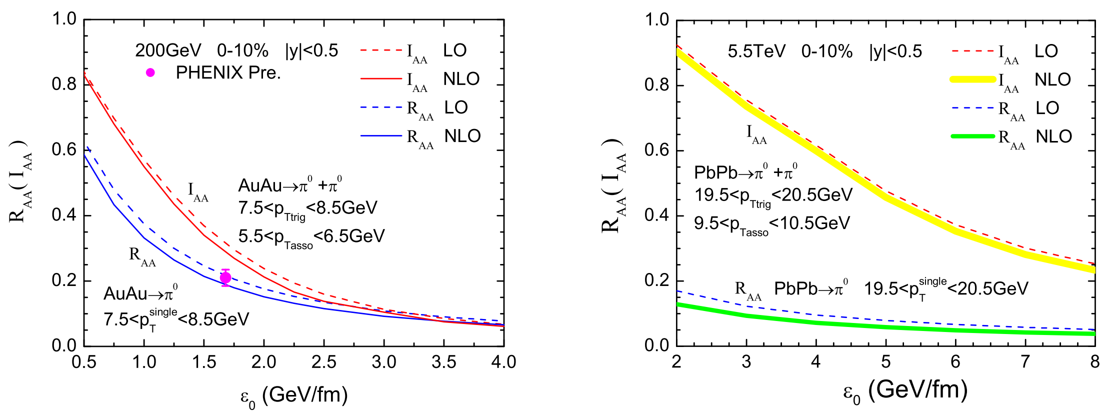

Figure 4. The suppression factors for single (R_{AA}) and dihadron (I_{AA}) spectra as a function of the initial energy loss parameter ϵ_0. The data are from Ref.[7].

distribution of the produced jets that have survived the interaction with the medium and whose leading hadrons contribute to the measured spectra. As pointed out in Ref. [9], when the initial gluon density is increased such that jets produced in the inner part of the overlapped region are completely suppressed, the final large p_T hadron production is dominated by "surface emission". Therefore, the suppression factor for single hadron spectra should never saturate but continue to decrease with the initial gluon density as shown in the left plot of Fig. 4. The dependence, nevertheless, becomes very weak when surface emission become dominant and single hadron suppression is no longer a sensitive probe of the the initial gluon density.

Fortrunately, in adjusting the energy loss parameter ϵ_0 or the initial gluon density ρ_0 to fit the suppression factors for both single hadron spectra and dihadron spectra, we find that dihadron spectra is much more sensitive to ϵ_0 than the single hadron spectra in the region $\epsilon_0 = 1 - 2$ GeV as shown in Fig. 1, Fig. 2 and the left plot of Fig. 4. One can understand this increased sensitivity of dihadron spectra in the spatial distribution of

the dijet production that survived interaction with the medium and contributed to the measured dihadron, as shown in the right plot of Fig. 3. Because of trigger bias, most of the contribution comes from dijets close and tangential to the surface of the overlapped region. However, there are still about 25% of the contribution coming from dijets near the center of the overlapped region. These jets are truely "punching" through the medium and survived the energy loss. As one further increases the initial gluon density, the fraction of these punch-through jets will also vanish and the final dihadron spectra will be dominated by the tangential jets in the outer corona. As shown in the left plot of Fig. 4, the dihadron suppression factor I_{AA} becomes identical to the single hadron R_{AA} and lose its sensitivity to the initial gluon density of the medium, as would be the case with p_T^{trig}=8GeV at the LHC energy. However, from a realistic estimate of the bulk hadron production at LHC, the energy loss parameter $\epsilon_0 \approx 5$GeV/fm in central $Pb+Pb$ collisions[10]. Of great excitements is in the right plot of Fig. 4 that a robust I_{AA} is again obtained while the R_{AA} becomes more fragile if the single and dihadron spectra at much higher p_T^{trig} (for example, p_T^{trig}=20GeV) are measured in LHC.

In summary, we have used NLO pQCD parton model with effective modified fragmentation functions due to radiative parton energy loss to study the fragility of both single and dihadron spectra as probes of the initial gluon density in high-energy heavy-ion collisions. Numerical analysis shows NLO contribution behaves with stronger quenching effect than LO contribution. Especially, we find the high p_T dihadron spectra are contributed not only by jet pairs close and tangential to the surface of the dense matter but also by substantial punching-through jets survived at the center of the dense matter while the single hadron high p_T spectra are only dominated by surface emission. Consequently, the suppression factor of such high-p_T hadron pairs is found to be more sensitive to the initial gluon density than the single hadron suppression factor.

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